J.C.T. 1-37

C. F. No. 3.4143-12
Prof.
Card Index

CIRCULAR NO. 459 April 1938
UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

EFFECTIVENESS OF IMPORTED INSECT ENEMIES OF THE SATIN MOTH

By T. H. JONES, *senior entomologist*, R. T. WEBBER, *associate entomologist*, and P. B. DOWDEN, *associate entomologist, Division of Forest Insect Investigations, Bureau of Entomology and Plant Quarantine* [1]

CONTENTS

	Page
Introduction	1
Investigations on the satin moth in Europe	2
Vienna, Austria	3
Ischgl, Austria	4
Budapest, Hungary	4
Oszro, Hungary	5
Nyiregyhaza, Hungary	5
The satin moth in the New England States	5
Introduction and spread	5
Food plants	5
Control factors operating previous to 1927	6
Effectiveness of introduced insect enemies	7
Effectiveness of other natural enemies	13
Conclusions regarding value of introduced insect enemies	14
Shipment of insect enemies of the satin moth from New England to Washington	15
The satin moth in the State of Washington	16
Introduction and spread	16
Food plants	16
Control factors operating previous to the introduction of parasites	17
Effectiveness of introduced natural enemies	17
Effectiveness of other natural enemies	21
Conclusions regarding value of introduced insect enemies	23
Summary and conclusions	23

INTRODUCTION

Soon after the satin moth (*Stilpnotia salicis* L.) was discovered in New England in 1920 it was noted that certain imported insect enemies were attacking the pest. These beneficial species had previously been imported from Europe as enemies of the gypsy moth (*Porthetria dispar* L.) and the brown-tail moth (*Nygmia phaeorrhoea* Don.). In 1926 the Bureau of Entomology established a sublaboratory at Budapest, Hungary. Partly because of the fact that two imported European species of parasites had already become important enemies of the satin moth in New England, the members of this sublaboratory were instructed to study the factors affecting the

[1] The writers wish to thank those who were members of the staffs of the laboratory and sublaboratory formerly maintained at Melrose Highlands, Mass., and Budapest, Hungary, respectively, and who assisted in securing information on the natural enemies of the satin moth. They wish especially to thank C. W. Collins, formerly in charge of the laboratory at Melrose Highlands, and R. C. Brown, who was formerly connected with this laboratory and the sublaboratory in Budapest, for helpful suggestions made in connection with the preparation of the manuscript. W. F. Sellers, while in charge of the Budapest sublaboratory from 1932 to 1934, inclusive, directed the work of securing satin moth parasites and shipping them to the United States. W. E. Ripper, of Vienna, Austria, played an important part in most of the European work with the satin moth while he was connected with the sublaboratory. In connection with data presented regarding Washington and Oregon, acknowledgment is made of the cooperation of the following members of the Bureau of Entomology and Plant Quarantine: F. P. Keen, C. F. Doucette, Randall Latta, W. W. Baker, C. E. Crumb, and J. W. Stanton. That portion of this circular relating to European investigations was prepared by P. B. Dowden, who spent several years at the sublaboratory at Budapest, Hungary; that portion having to do with the insect and its enemies in the New England States was written by T. H. Jones and P. B. Dowden; and that part dealing with conditions in Washington is the work of R. T. Webber and is based largely on observations which he made in the State in 1935.

25424°—38——1

FILE COPY
MISSOULA
FOREST INSECT
LABORATORY

insect in central Europe. Shipments of its insect enemies not already present in the United States were made to this country.

From 1929 to 1934, inclusive, insect enemies of the satin moth were liberated in the State of Washington. All species put out were of European origin, though some were already established in New England.

The information given in the following pages is in part a repetition of what has been given by those other writers whose publications are referred to. An attempt is here made to summarize the results of efforts to establish imported insect enemies of the satin moth in New England and Washington.

INVESTIGATIONS ON THE SATIN MOTH IN EUROPE

The satin moth is common throughout the whole of Europe. At times it is very abundant locally and severely defoliates poplar and willow, but it is not usually considered a very serious pest from an economic standpoint. Lombardy poplar (*Populus nigra italica* Du Roi), black poplar (*P. nigra* L.), and basket willow (*Salix viminalis* L.) are probably the most commonly defoliated species, while white poplar (*P. alba* L.) and other less common species of poplar and willow are fed on to a less extent.

Investigations of satin moth parasites, conducted from the subLaboratory at Budapest, were carried on at several different points in Hungary and Austria from 1927 through 1934. Attempts to secure egg parasites met with very little success. One species, *Telenomus mayri* Kieff., was reared in small numbers, but it was a factor of little importance in the control of the host during the years these observations were made. Collections of pupae also failed to produce any parasites of importance; in fact, only two specimens, one *Theronia atalantae* Poda and one *Ephialtes* sp., were reared from numerous pupal collections. Collections of larvae, on the other hand, indicated that there were a number of useful larval parasites. The hibernating larvae were severely parasitized by *Eupteromalus nidulans* Thoms. *Apanteles solitarius* Ratz. issued in fairly good numbers from the small larvae, and a number of different species of Tachinidae and Hymenoptera issued from the large larvae. *E. nidulans* was already established in the United States, and in 1927 a shipment of cocoons of *A. solitarius* resulted in the almost immediate establishment of this species. The work from 1928 to 1934, therefore, consisted almost exclusively of collecting full-grown or nearly full-grown larvae and holding them for the emergence of parasites. This work was supplemented considerably in 1933 and 1934 by field collections of two important parasites, *Meteorus versicolor* Wesm. and *Rogas unicolor* Wesm.

A list of the collections of large larvae of *Stilpnotia salicis* made from the Budapest laboratory, together with the numbers of the more important species reared, is given in table 1. The number of parasites listed does not by any means represent the total parasitization, however. In the first place, only large larvae were collected, so parasites of the small larvae were not represented and, in the second place, more than one tachinid puparium is often obtained from a single host larva. The list simply represents the results of this work over an 8-year period.

TABLE 1.—*Parasites of the satin moth reared and collected in central Europe, 1927–34*

Year	Point of collection	Large host larvae used in rearing	Parasites reared and collected						
			Meteorus versicolor	*Rogas unicolor*	*Carcelia gnava*	*Pales pavida*	*Tachina larvarum*	Miscellaneous	Malformed (undetermined)
		Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1927	Kelenvolgy, Hungary	1, 344			1, 024				
1928	Vienna, Austria	50, 000			1, 735	956	1, 622		
1929	do	90, 000	4, 107		3, 762	76	1, 907	225	476
1930	do	90, 000	2, 766		2, 509	5	2, 874	204	394
	Ischgl, Austria	18, 000			13, 249	79	2	29	972
1931	Budapest, Hungary	6, 000	2, 168	11	4	76	761		
1932	Nyiregyhaza, Hungary	24, 000			53	19	2, 098	48	33
	Oszro, Hungary	103, 500			1, 060		867	130	109
	Budapest, Hungary	26, 980	3, 420	286	13	2	64		1
1933	do	35, 950	9, 301	374	10	1	1, 052	24	9
1932	do		[1] 1, 934						
1933	do		[1] 5, 262	[1] 1, 890					
1934	do		[1] 6, 258	[1] 5, 075					

[1] Collected in the field.

It was impossible to make a detailed study of the various factors affecting the satin moth at the different points where large numbers of larvae were collected. Many of the points were visited only during the rearing season. The history of the pest at the different places is, however, of considerable interest, and parasites may have had a part in bringing about a reduction in some of the infestations.

VIENNA, AUSTRIA

In 1928 a satin moth infestation was located on a long row of large poplar trees in the vicinity of Vienna, near the Danube River. There were many rows and groups of poplars in the vicinity, and reports indicated that there had been some defoliation by the satin moth in 1926 and 1927, although previous to that time no infestations had been recorded. In 1928 it was estimated that a few trees were 50 percent defoliated. In 1929 the infestation was somewhat lighter and had moved along the row of poplars in a southerly direction. In 1930 the infestation was much lighter, larval collections were made with considerable difficulty, and it was believed that it would be impracticable to make collections in 1931. The area was visited in 1931 and 1932, and in both of these years it was estimated that it might have been possible to collect several thousand larvae at points some distance from the old infestation.

Data collected at the Budapest laboratory do not explain the gradual diminution in the satin moth infestations at Vienna. Parasitization of the large larvae collected for rearing purposes was low. In the fall of 1928 it was noted that the hibernating larvae were severely parasitized by *Eupteromalus nidulans*, and each year the number of cocoons of *Apanteles solitarius* encountered indicated that the species was important, but in the years that collections were made a high percentage of the large larvae pupated and produced adults.

ISCHGL, AUSTRIA

The infestation of *Stilpnotia salicis* near Ischgl, Austria, in 1930 was particularly interesting from the standpoint of climate and elevation. Groups of willows bordering a mountain stream for about 10 miles in the Paznaun Valley were found irregularly infested; some groups were entirely defoliated while others were not infested at all. The lowest point where *S. salicis* occurred was at Kappel, 4,425 feet, and the highest point at Mathon, 4,854 feet. The climate in this mountain valley is extremely varied. The ascent from the stream is very steep to the summit of the ridges, and these are covered with snow throughout the summer. Infestations near one another existed under varied conditions. At some points they were continuously in the shade while at others the sun shone for several hours each day. A heavy infestation occurred in the valley in 1929, but no definite information regarding former infestations could be found.

At a number of points defoliation was so severe that very many larvae starved. Parasitization was very high, but the collectors found that they could distinguish larvae containing maggots of *Carcelia gnava* Meig., and the collections do not represent a true picture of the amount of parasitization. Unfortunately the work could not be continued here in 1931. Melting snows plus very heavy thunderstorms during June caused the mountain river to rise rapidly and the infestation was swept away. It would have been most interesting to have determined the extent of the parasitization the next year. If the number of *Carcelia gnava* had increased it seems quite possible that this species might have checked the outbreak.

BUDAPEST, HUNGARY

Brown [2] has noted that the satin moth practically disappeared from a number of points in the vicinity of Budapest in 1929. No infestations have been noted at any of these points since that time.

In 1929 a satin moth infestation was located within the city limits of Budapest on a sand bar of the Danube River. This sand bar is about 2 miles long and from 100 to 200 yards wide. It supports a bushy growth of poplars from 3 to 8 feet in height. The infestation was never severe enough to defoliate more than a few clumps of bushes a year, but it persisted from 1929 through 1934, varying in intensity at different points. In 1934 the infestation was very light. An interesting feature of the infestation was the fact that, with the exception of 1933, each year it was under observation a partial second generation with complete development occurred. In 1933 only one second-generation larva could be found. All of the parasites reared from first-generation larvae, except *Rogas unicolor*, were also reared from those of the second generation. Collections of larvae were hardly large enough to indicate accurately the effect of parasitization, except in 1932 and 1933, and in those years only about 10 and 30 percent, respectively, of the collected larvae produced parasites. It is, however, very significant that such large collections of *Meteorus* and *Rogas* could be collected in the field in a light infestation, and it is believed that at this point parasites may have been important factors in holding the host in check.

[2] BROWN, R. C. OBSERVATIONS ON THE SATIN MOTH AND ITS NATURAL ENEMIES IN CENTRAL EUROPE. U. S. Dept. Agr. Cir. 176, 20 pp., illus. 1931.

OSZRO, HUNGARY

Oszro, in southern Hungary, was the center of a widely infested area in 1933. The country is flat, and there are many rows of tall poplar trees. More than 100,000 larvae were brought together, but most of them died of disease, and no estimate of the value of parasites could be made.

NYIREGYHAZA, HUNGARY

This infestation in Nyiregyhaza, Hungary, occurred on several rows of street trees in 1932. The spring was unusually early and warm that year and, although it was estimated on May 15 that 100,000 larvae could easily be brought together, on May 25 so many larvae had already pupated that only 24,000 were collected. This early development was unprecedented. Later it was found that there was a rather heavy second generation. In 1933 the infestation had so decreased that it was estimated that no more than 10,000 larvae could have been collected. The records are far too meager to permit judgment of the effect of parasites.

THE SATIN MOTH IN THE NEW ENGLAND STATES

INTRODUCTION AND SPREAD

The satin moth was first discovered in the United States in June 1920, when it was found defoliating Carolina poplars along a parkway near the Malden-Medford city line, a few miles north of Boston, Mass. Scouting operations during the summer of 1920 showed that the infestation was of several years standing and that the insect occurred over an area of 642 square miles, including 60 towns in Massachusetts and 4 in New Hampshire.[3]

In subsequent years the satin moth has spread, so that at present it is known to occur in approximately half of the total area of New England. While the spread has been principally towards the north and northeast, there has been a gradual dispersion towards the west and south, and in Massachusetts and Connecticut infestations have been found nearly to the New York line.

FOOD PLANTS

Until 1925 only poplars and aspens were noted to be heavily fed upon by the satin moth in New England. While Carolina poplar (*Populus deltoides* Marsh.) and Lombardy poplar (*P. nigra italica* Du Roi) first showed heavy defoliation, severe infestations later occurred on other species of the genus that occur more or less commonly in the infested area. These are balm-of-Gilead poplar (*P. balsamifera candicans* (Ait.) Gray), white poplar (*P. alba* L.) largetooth aspen (*P. grandidentata* Michx.), and quaking aspen (*P. tremuloides* Michx.). In 1925 heavy feeding on the foliage of willows was noted for the first time in New England, and since then has been observed frequently. While scrub oak (*Quercus ilicifolia* Wang.) and black oak (*Q. velutina* Lam.) were found to be partially favorable food plants in laboratory experiments, feeding on the foliage of trees other than those belonging to the genera *Populus* and *Salix* has not been reported as occurring in the field.

[3] BURGESS, A. F., and CROSSMAN, S. S. THE SATIN MOTH, A RECENTLY INTRODUCED PEST. U. S. Dept. Agr. Bull. 1469, 23 pp., illus. 1927.

Most of the feeding observed prior to 1929 was on trees planted for shade or ornamental purposes. During 1929 and the two following years defoliation of *Populus* was reported in a few woodland areas in southern New Hampshire. In those instances where the identity of the food plant was determined the species fed upon were *P. grandidentata* and *P. tremuloides*. Woodland infestations in New England have not been reported since 1931. Their occurrence during 1929 to 1931 was probably due to the fact that it was during those years that the satin moth reached a peak of abundance in localities where woodland growths of *Populus* are somewhat common. Their absence since 1931 is probably due to the fact that in subsequent years there has been a general marked decrease in the satin moth population in New England.

CONTROL FACTORS OPERATING PREVIOUS TO 1927

The first liberation of parasites imported from Europe specifically for the satin moth was made in New England in 1927. From the time when the insect was first noted in 1920, observations have been made to obtain information on the extent to which it is destroyed by beneficial insects. Burgess and Crossman [3] stated in 1927 that three species, previously introduced from Europe as enemies of the gypsy moth and brown-tail moth, attacked satin moth larvae in the field soon after the pest was known to be established. These species were the two tachinid flies *Compsilura concinnata* Meig. and *Sturmia scutellata* R. D. and the predacious carabid beetle *Calosoma sycophanta* L. Of these *C. concinnata* appeared to be the most important.

Burgess and Crossman further stated that rather limited observations had been made to determine the mortality of hibernating satin moth larvae in New England. Until the spring of 1926 it seemed to be slight. Examinations of hibernating larvae in several localities in the spring of 1926 showed 45 percent mortality. Of this they considered that 2.6 percent might be attributed to a fungus associated with a few of the dead larvae and 20.7 percent appeared to have been brought about by a small pteromalid parasite. The causes of the remaining 21.7 percent mortality was unaccounted for except that it was thought that part of it might have been due to mites. Adults of the pteromalid were determined as *Eupteromalus nidulans*, a parasite previously introduced from Europe as an enemy of the brown-tail moth.

Aside from the natural enemies referred to above, Burgess and Crossman listed several native parasites that had been secured from the eggs, larvae, and pupae of the satin moth in New England, and several birds that had been observed to feed on the larvae. With reference to the mortality of the hibernating larvae, they referred to the fact that in the area where observations were made no unusual winter temperatures had occurred during the years when the observations were made.

Besides the natural control factors that Burgess and Crossman mention as operating between 1920 and 1927, it is known that the methods of artificial control practiced in the area infested by the satin moth did much to reduce the numbers of the pest. The importance of such control is more readily understood in view of the fact that

[3] BURGESS, A. F., and CROSSMAN, S. S. THE SATIN MOTH, A RECENTLY INTRODUCED PEST. U. S. Dept. Agr. Bull. 1469, 23 pp., illus. 1927.

during these years the satin moth fed principally on trees planted for shade and ornamental purposes, and spraying for its control on such trees was carried on quite generally.

In spite of the natural enemies at work and the artificial control practiced, the satin moth was still continuing to increase and to spread into territory previously uninfested. It was therefore decided in 1927 to attempt the introduction of additional natural enemies from abroad.

EFFECTIVENESS OF INTRODUCED INSECT ENEMIES

It has already been stated that four introduced species of insects (*Compsilura concinnata*, *Sturmia scutellata*, *Eupteromalus nidulans*, and *Calosoma sycophanta*) were found attacking the satin moth in New England previous to 1927. Of these four only *Eupteromalus* and *Compsilura* have ever been found destroying enough satin moth larvae or pupae to be considered as important aids in controlling the pest.

EUPTEROMALUS NIDULANS

Proper [4] has given information concerning the value of *Eupteromalus nidulans* as a satin moth parasite. Beginning in 1928 he made examinations of satin moth hibernation webs in townships scattered

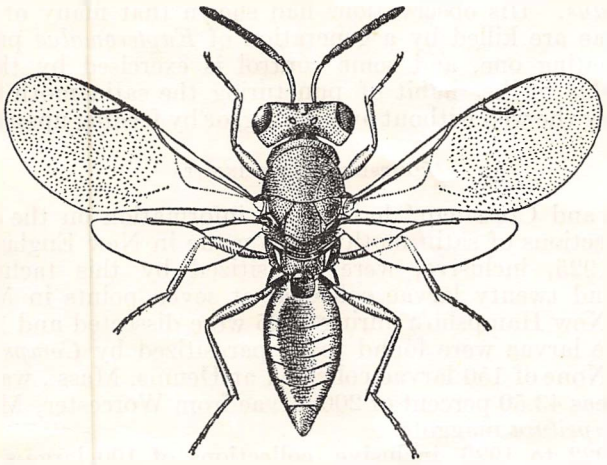

FIGURE 1.—Adult female of *Eupteromalus nidulans*, × 22. (Howard and Fiske.)

over the infested New England area to get information on the percentage of parasitization by *Eupteromalus*. The method used consisted in the opening of webs at each point visited and the recording of the contents, only live host larvae and parasite larvae being included in this count. It was the aim to examine at each point a total of 100 webs containing either live host larvae or live parasite larvae, but this was often not feasible because of the meager infestation.

The examinations begun by Proper in 1928 were continued for 8 years, either by him before his death in 1933 or by others. During the last 3 years, however, the number of townships visited was con-

[4] PROPER, A. B. EUPTEROMALUS NIDULANS, a PARASITE OF THE BROWN-TAIL AND SATIN MOTHS. Jour. Agr. Research 43: 37–56, illus. 1931.

siderably reduced, and examinations were practically limited to 5 selected points in each of 10 townships. The results obtained from the examinations made during the spring of each year from 1928 to 1935, inclusive, are given in table 2. Those for 1928 and 1929 have already been given by Proper in the paper previously referred to.

TABLE 2.—*Parasitization of satin moth larvae by Eupteromalus nidulans in New England*

Year	Townships where examinations were made	Living *Stilpnotia salicis* larvae found	Living *Eupteromalus nidulans* larvae found	Rate of parasitization by *Eupteromalus nidulans*	Year	Townships where examinations were made	Living *Stilpnotia salicis* larvae found	Living *Eupteromalus nidulans* larvae found	Rate of parasitization by *Eupteromalus nidulans*
	Number	*Number*	*Number*	*Percent*		*Number*	*Number*	*Number*	*Percent*
1928	10	941	126	11.8	1932	29	870	56	6.0
1929	21	1,521	153	9.1	1933	12	1,729	257	12.9
1930	22	1,352	354	20.7	1934	9	527	54	9.2
1931	23	925	272	22.7	1935	6	109	21	16.1

As pointed out by Proper, such figures as are given in table 2 are only attempts to approximate the percentage of parasitization of hibernating satin moth larvae by the hibernating generation of *Eupteromalus*. His observations had shown that many of the satin moth larvae are killed by a generation of *Eupteromalus* previous to the hibernating one, and some control is exercised by the female *Eupteromalus* by her habit of puncturing the satin moth larva and then leaving the web without ovipositing, or by feeding upon the larva.

COMPSILURA CONCINNATA

Burgess and Crossman [5] have given information on the extent to which collections of satin moth larvae made in New England during 1922 to 1925, inclusive, were parasitized by this tachinid. Six hundred and twenty larvae collected at seven points in Massachusetts and New Hampshire during 1925 were dissected and 16.94 percent of the larvae were found to be parasitized by *Compsilura concinnata*. None of 150 larvae collected at Dennis, Mass., was parasitized, whereas 43.50 percent of 200 larvae from Worcester, Mass., contained *Compsilura* maggots.

From 1922 to 1929, inclusive, collections of 100 large-sized satin moth larvae were made each year in Revere, Melrose, and Medford, Mass. Large-sized larvae were collected because it is at this time that larvae are most apt to be parasitized by *Compsilura*. The collections were kept in trays in the laboratory and cared for until all parasites had emerged. The numbers of *Compsilura* obtained from these collections are shown in table 3.

Revere, Melrose, and Medford are in the immediate vincinity of Boston, and the points where the collections were made are, at most, only about 6 miles apart. The figures given in table 3 indicate that *Compsilura* was a common parasite of the satin moth in this section

[5] BURGESS, A. F., and CROSSMAN, S. S. See footnote 3.

TABLE 3.—*Parasitization of satin moth larvae by Compsilura concinnata in Revere, Melrose, and Medford, Mass., 1922–29*

Year	*Compsilura concinnata* reared from lots of 100 large satin moth larvae collected at—			Year	*Compsilura concinnata* reared from lots of 100 large satin moth larvae collected at—		
	Revere	Melrose	Medford		Revere	Melrose	Medford
	Number	*Number*	*Number*		*Number*	*Number*	*Number*
1922	11	44	50	1926	11	82	29
1923	7	71	63	1927	61	181	17
1924	56	66	71	1928	24	9	33
1925	7	9	51	1929	11	96	44

from 1922 to 1929, and it seems safe to assume that the same was true in previous and subsequent years. They further indicate that the tachinid was as effective at the time the satin moth was first dis-

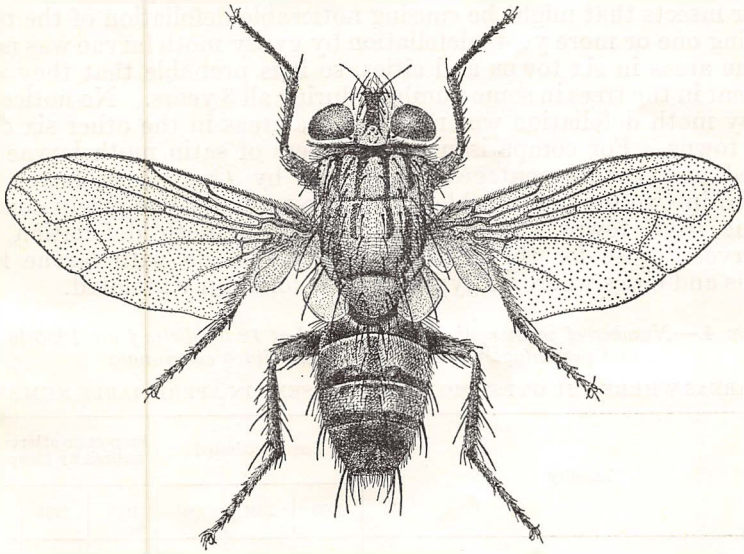

FIGURE 2.—Adult female of *Compsilura concinnata*, × 6½. (Burgess and Crossman.)

covered in New England as it has been since. The number of *Compsilura* reared from any collection cannot be considered to be the same as the number of larvae parasitized because of the fact that more than one maggot of the fly may issue from a single host larva. This is apparent from the results obtained from the collection of 100 larvae made in Melrose in 1927. A total of 181 *Compsilura* issued, yet one moth issued, and it is not known that all other individuals were parasitized.

Other collections of satin moth larvae made at various points in the infested New England area have indicated that *Compsilura* is commonly parasitic on the larvae throughout the region.

Compsilura is not able to overwinter in satin moth larvae. Its effectiveness as a parasite of the satin moth in any particular area must, therefore, depend in part on the larval population of other species in which it can pass the winter. Another factor that would appear to influence its effectiveness as a parasite of the satin moth in any locality is the number of larvae of hosts other than the satin moth suitable for parasitization at the same time as are the satin moth larvae. The gypsy moth is one of the other preferred hosts. Burgess and Crossman [6] have stated that, whereas collections of gypsy moth larvae were made for the purpose of securing *Compsilura* for colonization, satisfactory results were also secured from collections of satin moth larvae made in an area where the gypsy moth was not abundant. During 1933, 1934, and 1935, collections of large satin moth larvae were made when possible in designated areas in 12 New England towns and cities. These larvae were later dissected to secure information on the parasites they might contain. When making the collections the collectors were expected to make certain notes, including therein reference to any other insects that might be causing noticeable defoliation of the trees. During one or more years defoliation by gypsy moth larvae was noted in the areas in six towns and cities, so it is probable that they were present in the trees in some numbers during all 3 years. No noticeable gypsy moth defoliation was noted in the areas in the other six cities and towns. For comparison the numbers of satin moth larvae collected and the percentages parasitized by *Compsilura* have been placed in two groups in table 4. The records for one group concern larvae from towns and cities where gypsy moth defoliation was observed; those for the other group have to do with larvae from towns and cities where no gypsy moth defoliation was noted.

TABLE 4.—*Number of satin moth larvae collected at 12 localities from 1933 to 1935 and percentage parasitized by Compsilura concinnata*

Locality	Larvae collected			Proportion of larvae parasitized by *Compsilura*		
	1933	1934	1935	1933	1934	1935
	Number	*Number*	*Number*	*Percent*	*Percent*	*Percent*
IN AREAS WHERE THE GYPSY MOTH WAS PRESENT IN APPRECIABLE NUMBERS						
Augusta, Maine	237	14	10	0.8	0	0
Portland, Maine	294	243	192	3.7	2.4	0
Ashland, N. H.	426	228	58	.7	0	0
Conway, N. H.	100	34	4	0	0	0
Concord, N. H.	500	286	289	0	.3	0
Dennis, Mass.	23	15	3	0	0	0
IN AREAS WHERE THE GYPSY MOTH WAS NOT PRESENT IN APPRECIABLE NUMBERS						
Bangor, Maine	500	34	46	7.2	38.2	0
Skowhegan, Maine	100	-------	-------	7.0	-------	-------
Kingston, N. H.	100	-------	-------	8.0	-------	-------
Fitchburg, Mass.	126	137	308	11.1	5.8	.3
Medford, Mass.	242	405	500	6.6	5.9	3.6
Woonsocket, R. I.	432	260	86	6.2	26.5	20.1

[6] BURGESS, A. F., and CROSSMAN, S. S. IMPORTED INSECT ENEMIES OF THE GIPSY MOTH AND THE BROWN-TAIL MOTH. U. S. Dept. Agr. Tech. Bull. 86, 148 pp., illus. 1929.

It will be noted from table 4 that the percentages of parasitization of satin moth larvae were lower in those areas where the gypsy moth was present in appreciable numbers than in those areas where it was not. It is believed that this was due to the difference in gypsy moth population in the areas. Satin moth larvae and gypsy moth larvae, suitable for parasitization by *Compsilura concinnata*, occur in the field at the same time of year. It is to be expected, therefore, that satin moth larvae would be more heavily parasitized by *Compsilura* in areas where gypsy moth larvae are scarce than in areas where they are abundant.

APANTELES SOLITARIUS

Apanteles solitarius is the third important introduced parasite of the satin moth in New England. Unlike *Eupteromalus nidulans* and *Compsilura concinnata*, which were already firmly established in the area when the satin moth was discovered to be present in 1920, *Apanteles solitarius* was imported from Europe especially as a satin

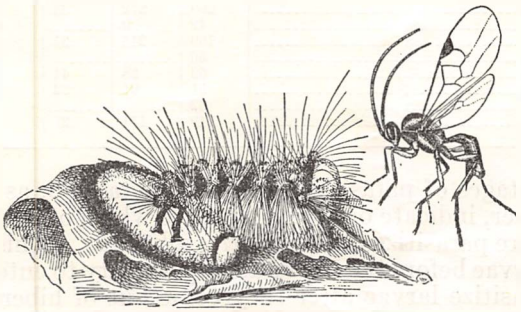

FIGURE 3.—Adult female and cocoon of *Apanteles solitarius*, × 7. (Howard and Fiske.)

moth parasite. It was first liberated in 1927. Parker [7] has published a bulletin concerning the species in which he discusses its effectiveness as a parasite of hibernating satin moth larvae in New England, based largely on examinations made in 1932 and 1933.

Apanteles solitarius became quickly established in New England after it was liberated in 1927, and by 1930 it was recovered in promising numbers from satin moth larvae collected in a number of localities in Massachusetts and New Hampshire. Parker includes the following paragraph in the summary of his bulletin, which was based on information secured previous to 1934:

> Collections from several towns indicate rapid spread of the parasite and that it is now apparently distributed over the territory in New England infested with the satin moth. From a study of the hibernating form of the host, it is shown that *Apanteles solitarius* effected a parasitization of 14.5 to 66.7 percent, and in 12 of the 15 towns in which observations were made the percentage of parasitization was greater than 40 percent.

In 1933 definite points were selected in 12 New England cities and towns for the purpose of studying fluctuations in satin moth population and natural enemies. The trees at some of these points were cut down before these studies were brought to a close in 1935, and it was

[7] PARKER, D. L. APANTELES SOLITARIUS (RATZEBURG), AN INTRODUCED BRACONID PARASITE OF THE SATIN MOTH. U. S. Dept. Agr. Tech. Bull. 477, 18 pp., illus. 1935.

not possible to make collections of hibernating larvae each season at all of the points during the period they were under observation. Dissections of those collections of hibernating larvae that were made showed the parasite present in all but one. In the other collections the percentage of parasitization ranged from 3 to 73 percent. The results are given in table 5.

TABLE 5.—*Number of satin moth larvae collected at 12 localities from 1933 to 1935 and percentage parasitized by Apanteles solitarius*

Locality	Larvae collected			Proportion of larvae parasitized by *Apanteles*		
	1933	1934	1935	1933	1934	1935
	Number	*Number*	*Number*	*Percent*	*Percent*	*Percent*
Portland, Maine	178	308	33	45	54	9
Augusta, Maine	20	140		10	15	
Bangor, Maine	143	131		0	5	
Skowhegan, Maine	23	8		4	25	
Ashland, N. H	269	272	33	19	50	6
Conway, N. H	42	9		47	55	
Concord, N. H	169	215	35	27	49	8
Kensington, N. H	30			73		
Fitchburg, Mass	69	88	44	3	21	11
Medford, Mass	51	91	52	17	23	8
Dennis, Mass	32			6		
Woonsocket, R. I	149	174	21	6	12	9

The percentages of parasitization given in table 5, as well as those given by Parker, indicate only the extent to which overwintering satin moth larvae are parasitized by *Apanteles solitarius*. This parasite also issues from larvae before they have an opportunity to enter hibernation and may parasitize larvae after they come out of hibernation in the spring. The amount of parasitization shown by the dissection of hibernating larvae is only an indication of total usefulness.

Parker considered *Apanteles solitarius* an effective agent in the reduction of a satin moth infestation, partly because it is capable of maintaining itself when the infestation is low in intensity. Table 5 shows that it was present in all except one of the collections dealt with, and the fact that some of these collections contained only a few larvae adds additional evidence to Parker's contention. Since *A. solitarius* became generally distributed over the territory in New England infested with the satin moth, it has been much more commonly met with in satin moth infestations than have *Eupteromalus nidulans* and *Compsilura concinnata*.

OTHER INTRODUCED SPECIES

In connection with the introduction of natural enemies of the gypsy moth, brown-tail moth, and satin moth into New England, a number of other species have been liberated which are known to attack the satin moth in Europe. These species are either not known to be established or, if established, are of no consequence in the control of the satin moth.

From 1927 to 1934, inclusive, 20,000 adults of *Meteorus versicolor*, 15,085 adults of *Carcelia gnava*, and 3,134 adults of *Rogas unicolor* were liberated in satin moth infestations. A few *Meteorus* larvae and one *Rogas* larva have been dissected from satin moth larvae, but there

is no evidence that either of these species or *Carcelia gnava* is established.

Smaller numbers of *Tachina larvarum* L., *Zenillia libatrix* Panz., and *Pales pavida* Meig. have been liberated at points where the satin moth was abundant and numbers have been liberated elsewhere with the hope that they might become established as enemies of the gypsy moth or brown-tail moth.[8] None of these tachinid flies has ever been recovered in New England.

Burgess and Crossman[9] stated that adults of the carabid beetle *Calosoma sycophanta* L. "are often seen climbing over the trees and feeding on satin moth larvae," and that the tachinid *Sturmia scutellata*, which they mentioned under the generic name of *Blepharipa*, had "attacked satin moth larvae in the field." There is no proof, however, that either of these introduced species has ever been an important enemy of the satin moth in New England. Field observations and examinations and rearings of the many collections of larvae and pupae have shown them to be of very little consequence in this respect. This is especially true of *S. scutellata*. An imported egg parasite (*Schedius kuvanae* How.) of the gypsy moth has also been reared in negligible numbers from satin moth eggs.

EFFECTIVENESS OF OTHER NATURAL ENEMIES

A number of native parasites have been reared from eggs, larvae, or pupae of the satin moth collected in New England, but they have been met with in such small numbers that they cannot be considered of any importance as enemies of the pest. They are listed below mainly for the benefit of those particularly interested in insect parasites.

Reared from satin moth eggs:

Telenomus californicus Ashm.
Trichogramma minutum Riley

Reared from satin moth larvae or pupae:

Ephialtes conquisitor Say
E. pedalis Cress.
Theronia fulvescens Cress.
Dibrachys hemerocampae Gir.
Psychophagus omnivorus Walk.
Exorista mella Walk.
Zenillia blanda O. S.
Phorocera claripennis Macq.
Carcelia laxifrons Vill.

A mite, presumably *Pediculoides ventricosus* Newp., has at times been found in some numbers feeding on hibernating satin moth larvae in the field in New England, and it is probable that in some areas it sometimes destroys enough such larvae to raise it to the level of an important natural enemy. Brown[10] stated that *Pediculoides ventricosus* brought about the complete and rapid annihilation of a satin moth infestation he had under observation in Budapest, Hungary.

Burgess and Crossman[11] state that birds undoubtedly consume many larvae of the satin moth in New England. They list the following species as having been observed feeding on the larvae: Black-billed

[8] BURGESS, A. F., and CROSSMAN, S. S. See footnote 6.
[9] ——, and CROSSMAN, S. S. See footnote 3.
[10] BROWN, R. C. See footnote 2.
[11] BURGESS, A. F., and CROSSMAN, S. S. See footnote 3.

cuckoo (*Coccyzus erythrophthalmus* Wils.), Baltimore oriole (*Icterus galbula* L.), blue jay (*Cyanocitta cristata cristata* L.), starling (*Sturnus vulgaris* L.), and catbird (*Dumetella carolinensis* L.).

Two entomophagous fungi, *Beauveria globulifera* (Spegazzini) Picard and *Isaria farinosa* (Dickson) Fries, have been found on dead larvae of the satin moth, collected from beneath their hibernation webs.[12] No special effort has been made to determine the percentage of hibernating larvae so attacked, but it is believed that in some infestations it was rather high during certain years. It is presumed that the rapid spread of disease caused by these fungi is largely dependent upon favorable weather conditions. Brown[13] states that at three points in Hungary *Beauveria globulifera* and *Isaria farinosa* were apparently the factors which brought about the control of the satin moth.

Unusually low winter temperatures sometimes kill large numbers of hibernating satin moth larvae in New England. It is known that this was particularly true during the winter of 1933–34. The United States Weather Bureau recorded minimum temperatures of −18° F. at Boston, Mass., and Portland, Maine, and lower temperatures at other stations within the infested area.[14] The mean temperature for the New England section for December 1933 was the third lowest since 1888, and February 1934 was the coldest month ever recorded since the compilation of averages for the section.

CONCLUSIONS REGARDING VALUE OF INTRODUCED INSECT ENEMIES

From information obtained by the Bureau of Entomology and Plant Quarantine and given in part in the Insect Pest Survey Bulletin summaries from 1927 to 1935, inclusive, it appears that the satin moth continued to increase its numbers and range in New England from the time it was first discovered in 1920 until it reached a peak in 1930 or 1931. Generally speaking, defoliation was much less severe from 1932 to 1934, inclusive. Records obtained during the summer of 1935 indicated that the pest was again on the increase.

So far as known, unusually severe winter temperatures, three introduced insect enemies (*Compsilura concinnata*, *Eupteromalus nidulans*, and *Apanteles solitarius*), and possibly fungous disease are the only factors, other than spraying, which have at any time destroyed sufficient numbers of the satin moth in New England to be important in the control of the pest.

While low temperatures destroyed large numbers of hibernating larvae during the winter of 1933–34, there is no evidence that this was true in previous years. Since the satin moth had begun to decrease in numbers previous to 1933, some other factor or factors must have brought this about.

Spraying has undoubtedly been of great benefit in protecting poplar and willow trees from defoliation and it no doubt was an important factor in reducing the numbers of the pest when feeding was restricted to trees planted for shade or ornamental purposes in areas where measures for the control of insect pests are generally employed. Once it got beyond such areas and into woodland areas, as it is known

[12] Determined by W. H. Sawyer, Jr., Bates College, Lewiston, Maine.
[13] Brown, R. C. See footnote 2.
[14] United States Weather Bureau. Climatological Data, New England Section. v. 45, no. 12, pp. 67–72, 1933; v. 46, no. 2, pp. 7–12, 1934.

to have done to a limited extent from 1929 to 1931, inclusive, the spraying that was done would hardly be expected to be such an important factor in reducing the numbers of the satin moth in the areas infested by it.

Of the three introduced enemies, two (*Compsilura concinnata* and *Eupteromalus nidulans*) were thoroughly established throughout the region before the satin moth was discovered in 1920, and it is not believed that they have become increasingly important enemies of it from year to year. It is reasonable to expect that certain local conditions, such as populations of their other hosts, have governed the extent to which they have acted as parasites of the satin moth.

Two other factors remain to be considered. Lack of information makes it impossible to render an opinion as to what importance fungous disease may have had in bringing about the reduction of satin moth population that was first apparent in 1932. It may not have been at all responsible, or, on the other hand, it may have been most important.

Finally it is significant that the third important introduced parasite (*Apanteles solitarius*) of the satin moth was first recovered in promising numbers in 1930 and in subsequent years continued to parasitize good percentages of larvae. It may be that its addition as a control factor was sufficient to reduce at least temporarily the numbers of the pest to such a degree that it became much less noticeable and injurious from 1932 to 1934, inclusive.

SHIPMENT OF INSECT ENEMIES OF THE SATIN MOTH FROM NEW ENGLAND TO WASHINGTON

From 1929 to 1934 the Bureau of Entomology and Plant Quarantine sent shipments of several species of insect enemies of the satin moth from New England to Washington for liberation. These sendings were made from the Bureau's laboratory formerly located at Melrose Highlands, Mass., and handled in Washington by members of the Bureau who were stationed in that State. Proper precautions were taken to prevent the escape of hyperparasites.

Adults of *Meteorus versicolor*, *Rogas unicolor*, *Carcelia gnava*, *Tachina larvarum*, and *Zenillia libatrix* that were sent to Washington had issued from cocoons and puparia that came to Melrose Highlands from Europe, and a limited number of puparia of *Pales pavida* from the same source were forwarded. In those cases where adults were sent, the mortality en route to Washington was high in some of the lots. This was particularly true with the tachinid flies.

Adults of the carabid beetle *Calosoma sycophanta* were collected in the field in New England and sent to Washington. Adults of *Apanteles solitarius* and puparia of *Compsilura concinnata* were also shipped. The *Apanteles* adults issued in the laboratory from cocoons collected in the field, while the *Compsilura* puparia were formed by maggots that issued from larvae of the gypsy moth and satin moth that had been collected in the field in large numbers and placed in trays.

Eupteromalus nidulans adults were also shipped to Washington for liberation. *Eupteromalus* commonly hibernates as a mature larva in the hibernating web of the brown-tail moth. From 1931 through 1934 large collections of these webs were made in New England and held in cold storage until the middle of July. They were then removed

and placed in wooden trays, in the front side of each of which there were several holes 1 inch in diameter. Light was excluded from the trays except that which entered the holes. The open ends of glass shell vials were inserted in these openings, and as the brown-tail moth larvae became active and left the webs they entered the vials and were taken out and destroyed. The *Eupteromalus* adults which later issued from the webs were also attracted to the light, and as they entered the vials they were removed and placed in containers for shipment.

THE SATIN MOTH IN THE STATE OF WASHINGTON

INTRODUCTION AND SPREAD

The satin moth was first discovered in Washington at Bellingham in 1922 by W. E. Longley, and subsequent scouting under the direction of A. G. Webb of the Bureau of Entomology and Plant Quarantine revealed many local infestations throughout the western part of the State. Since its establishment the species has extended its range considerably, principally in a southerly direction. In Washington it has dispersed practically over the entire section west of the Cascade Range and southward into Oregon. According to F. P. Keen, the result of the scouting of 1935 in Oregon shows numerous infestations in the Willamette Valley as far south as Albany, Linn County. This is an approximate southward dispersal of over 300 miles in 13 years. So far as known *Stilpnotia salicis* does not occur in eastern Washington or eastern Oregon.

FOOD PLANTS

During 1935 partial to complete defoliation of the following species was observed in certain areas:

White poplar	*Populus alba* and varieties.
Lombardy poplar	*P. nigra italica.*
Carolina poplar	*P. deltoides.*
Northern black cottonwood	*P. trichocarpa hastata* (Dode) Henry.
Scouler willow	*Salix scouleriana* Barr.
Western black willow	*S. lasiandra* Benth.
Golden willow	*S. vitellina* L.

The preference of the species for a certain host plant was much more evident during the first year of its establishment. According to the observation of C. F. Doucette and Randall Latta, there has been a gradual shifting of the satin moth infestation from the introduced poplars to the native cottonwoods and willows. This is not without exception, however, for infestations still persist on the introduced poplars throughout the old infested region. In Oregon F. P. Keen reports a decided preference for the introduced poplars, with *Populus alba* first in order, followed by Lombardy poplar and Carolina poplar. Native poplars and willows are mentioned as "occasionally fed upon."

So far as the introduced poplars and the native willows are concerned, they do not appear to have suffered much injury from the satin moth. Authentic records of complete defoliation for 2 successive years are common and the condition of the trees is still good.

The adaptation of the satin moth to the native cottonwood (*Populus trichocarpa hastata*) and its tendency to persist thereon is, however, of significant interest. This species is found abundantly in the Puget Sound section and, although unimportant commercially, it is, nevertheless, a beautiful ornamental. In some cases repeated defoliations

have undoubtedly hastened the death of poorly conditioned trees while other, sound trees have probably been considerably weakened. It is certain from the observations of 1935 that at times even a single defoliation of the native cottonwood is injurious.

CONTROL FACTORS OPERATING PREVIOUS TO THE INTRODUCTION OF PARASITES

No intensive study was made of the satin moth in Washington previous to 1935, and little is known of the control factors operating before that time. The present study has revealed several factors which were probably influential in this respect but obviously inadequate, since the species has persisted in such abundance. So far as natural enemies are concerned, about the only data available are in connection with field observations and some larval collections made during the years 1928–34. These collections, which aggregate approximately 3,500 larvae, were made for recovery of parasites and are of no importance except to indicate the presence of two native tachinid parasites (table 6).

TABLE 6.—*Results of dissections of satin moth larvae collected in Washington, 1928–34*

Year	Larvae dissected	Instar of larvae	Parasites obtained		Year	Larvae dissected	Instar of larvae	Parasites obtained	
			Tachinomyia similis Will.	*Exorista mella* Walk.				*Tachinomyia similis* Will.	*Exorista mella* Walk.
	Number		*Number*	*Number*		*Number*		*Number*	*Number*
1928	498	Last	4	8	1933	200	Last	0	4
1930	1,005	do	0	0	1934	600	Intermediate	0	1
1931	1,114	do	0	68					

Artificial control has undoubtedly been responsible for a large decrease of the moth in certain urban areas, but its influence is purely local and has had little or no effect in general.

EFFECTIVENESS OF INTRODUCED NATURAL ENEMIES

Since the control factors operating in the region were apparently inadequate, additional aid was deemed necessary to check the ravages of *Stilpnotia salicis*. During 1929–34 10 parasitic species of European origin were liberated at various localities within the infested territory in Washington. This material was obtained from the forest insect laboratory formerly located at Melrose Highlands, Mass., and was liberated by C. F. Doucette and others. A summary of the liberations is given in table 7.

TABLE 7.—*Introduced species of satin moth parasites liberated in Washington, 1929–34*

Species	Years of liberation	Adults liberated	Species	Years of liberation	Adults liberated
		Number			*Number*
Apanteles solitarius	1932	267	*Zenillia libatrix*	1932	2
Meteorus versicolor	1932–34	5,590	*Carcelia gnava*	1932–33	95
Eupteromalus nidulans	1931–34	11,727	*Pales pavida*	1932	38
Rogas unicolor	1934	1,876	*Tachina larvarum*	1933	605
Compsilura concinnata	1929–34	6,924	*Calosoma sycophanta*	1929–30	428

The locations of the colony sites are shown in figure 4.

The recovery and dispersion of the parasites, as well as their effectiveness, were determined by the usual methods. Satin moth larvae and pupae were collected at all of the places of parasite liberations and elsewhere in localities where material was obtainable. A number of points, representative of various environments and growth, were selected for close observation. Random samples of hibernacula were taken from these points in the spring before emergence and in the fall of the year after the larvae had entered hibernation. By this procedure data for two seasons were obtained and classified as shown in table 8. Since the fall collections were made so shortly after the beginning of hibernation, the number of larvae dead of unknown cause is probably much less than normal.

TABLE 8.—*Results of examinations (1 hour each) of satin moth hibernacula made during the spring and fall of 1935*

Location of observation point	Spring collections					Fall collections				
	Hibernacula examined	Proportion of larvae killed by—				Hibernacula examined	Proportion of larvae killed by—			
		Apanteles solitarius	*Meteorus versicolor*	*Eupteromalus nidulans*	Unknown cause		*Apanteles solitarius*	*Meteorus versicolor*	*Eupteromalus nidulans*	Unknown cause
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*
Hoquiam	125	0	0	0	5	184	6	0	0	4
Elma	52	4	0	0	27	92	10	0	4	1
Longview	59	5	0	0	42	149	30	0	0	6
Centralia	120	26	2	0	23	122	13	2	0	8
Yelm A	48	17	0	0	40	2	0	0	0	0
Greendale	122	6	2	1	33	146	1	1	1	1
Puyallup A	30	7	0	0	20					
Puyallup B	148	8	3	0	22					
Sumner A	131	17	7	0	15	103	19	31	0	5
Sumner B	68	24	1	0	15					
McMillen	73	7	3	0	12					
Redmond A	80	14	0	0	11	82	15	2	2	10
Redmond B	120	6	0	0	53	158	13	3	1	18
Yelm B						114	26	0	2	4
Everett						82	14	7	0	0
Marysville A						134	55	0	0	2
Olympia						108	15	0	0	6
Stanwood						126	2	0	0	13
North Tacoma						116	17	2	0	5

EUPTEROMALUS NIDULANS

The only recovery of *Eupteromalus nidulans* during the spring of 1935 was made by W. W. Baker at Greendale, a few miles southwest of the colony site at Lakeview. Additional attempts to recover the species here and elsewhere in the vicinity were without avail. The second recovery of *Eupteromalus* was made during the fall of 1935 at Elma, about 20 miles west of South Olympia, the nearest point of liberation. Subsequently the recovery of *Eupteromalus* was recorded from Yelm, Greendale, and two localities in Redmond. Redmond, which is the northern limit of dispersion, is about 20 miles south of Everett, the nearest point where the parasite was liberated.

The establishment of *Eupteromalus* is of too recent occurrence to have any appreciable effect upon *Stilpnotia salicis*. In the five locali-

ties from which it was recovered (table 8) only a small amount of parasitization was registered. Moreover, 474 additional hibernacula were examined from the same localities and these proved even less productive of *Eupteromalus* than the first.

COMPSILURA CONCINNATA

Compsilura concinnata was first recovered in the spring of 1933 by W. W. Baker from an unknown lepidopteron collected at Puyallup in 1932. During 1935 approximately 7,000 last-instar larvae were collected from 38 localities for the purpose of ascertaining the dispersion and parasitization by *Compsilura*. Recoveries of the species

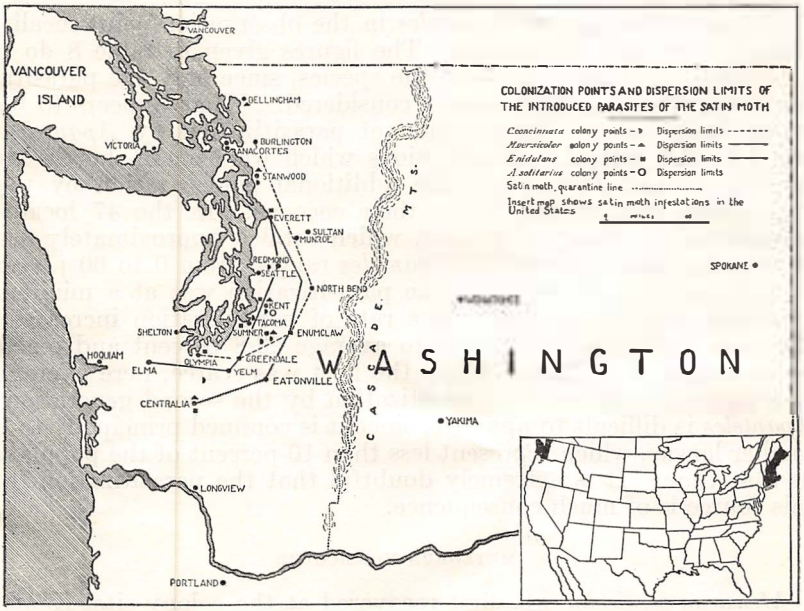

FIGURE 4.—Colonization points and dispersion limits of the introduced parasites of the satin moth in Washington.

from 15 localities were, without exception, traceable to liberations within 20-mile radii. Dispersion has not been as rapid as was expected, although so far as can be seen a favorable environment exists. Certainly there is sufficient deciduous growth and acreage devoted to market-garden crops to support suitable host species. It is possible, perhaps, that the extensive growth of conifers typical of the section acts as a barrier, since such growth is practically free of favorable host species.

During 1935 the parasitization by *Compsilura* in the area of its recovery ranged from 0.3 to 43 percent. The species was abundant in only two localities, both of which were within the city limits of Tacoma. In these localities the parasitization ranged from 34 to 43 percent, a fact probably due to a concentration of the parasite on comparatively few *Stilpnotia salicis*.

APANTELES SOLITARIUS

The history of *Apanteles solitarius* in Washington is most amazing. It seems incredible that from a single colony consisting of 80 males and 187 females liberated at Kent June 6, 1932, the species could in so short a time increase in such proportions and disperse over so large a territory. According to a survey made by Randall Latta in May 1934, *A. solitarius* could be found in variable abundance all over the principally infested areas in Washington. To this may be added the writer's observation that *Apanteles* cocoons, formed in 1934 or earlier, have been found in every satin moth infestation visited by him. The dispersal of *A. solitarius* within 2 years of its liberation to apparently isolated infestations 100 or more miles distant is most noteworthy.

The parasitization by *Apanteles* in the observation-point localities ranged from 0 to 55 percent. The figures given in table 8 do not reveal the true effectiveness of the species, since only the parasitization by overwintering larvae is considered. What appears to be a better basis for the computation of parasitization by *Apanteles* is found in the early larval collections which were made shortly after emergence, and hence show the additional parasitization by those individuals that overwinter in their cocoons. In the 47 localities represented by these collections, which totaled approximately 3,400 larvae, the parasitization by *Apanteles* ranged from 0 to 60 percent. In the heavily infested areas the parasitization was at a minimum, averaging only 11 percent. The rate of parasitization increased in the more lightly infested areas to average 23.8 percent and reached its maximum in localities where the host was scarce, here averaging 32.8 percent. Additional parasitization by the second generation of *Apanteles* is difficult to appraise, since it is confined principally to the smaller larvae, which represent less than 10 percent of the population at that time. It is extremely doubtful that the parasitization from this source is of much consequence.

METEORUS VERSICOLOR

Meteorus versicolor was first recovered at the colony site, Kent, in 1933, the year following its liberation. In 1934 it was recovered at Thomas, an adjacent town, and at Auburn, 5 miles to the south. *Meteorus* was liberated at Sumner, about 7 miles south of Auburn, in 1933 and recovered in 1934. Other colonies were liberated in 1934, but at only one of them, in Centralia, was the species recovered. Directly traceable to the Kent and Sumner colonies are the recoveries made at the following places during 1935: Renton, Medina, Kirkland, Redmond, Everett, Fall City, Enumclaw, Puyallup, McMillen, Tacoma, Greendale, East Greendale, Graham, and Eatonville. These recoveries indicate a dispersion of about 50 miles in a northerly direction and about 25 miles southward. It seems safe to say that since its liberation *Meteorus* has become established over the entire eastern Puget Sound section from Everett on the north to Olympia on the west and to Centralia on the south. In all probability it has dispersed to the eastern range of the satin moth in Washington.

Unfortunately there was no infestation in several of the observation-point localities in the fall of 1935 and in the other places the recoveries of *Meteorus* were such that they offer little aid for comparative study.

About all that can be said is that in 10 of the 19 observation-point localities shown in table 8 from which *Meteorus* was recovered the parasitization ranged from 1 to 31 percent. Additional data are available, however, from the early larval collections, which show that the parasitization by *Meteorus* in six other localities ranged from 1 to 20 percent.

During 1935 the parasitization by both generations of *Meteorus* ranged from 0.4 to 50 percent over the known region of its dispersal.

Field observations offer excellent proof of the aggressiveness of this species. The infestation at Kent has practically disappeared, and there is not the slightest doubt that *Meteorus* was an important factor in this result. This is evidenced by the numerous old cocoons still attached to the tree trunks. It was difficult to collect 100 early-instar satin moth larvae in the locality, and the results of their dissection showed that 20 percent of them contained *Meteorus* larvae. Furthermore, the larvae were so reduced in numbers that by the time they had reached the last instar only 10 could be found, and 5 of these produced *Meteorus*.

Another good example of the effectiveness of *Meteorus* is evidenced at Sumner. The satin moth infestation was first noted in this locality in 1933, and has increased its proportions each year and, so far as can be ascertained by comparative data, would not have reached its peak until 1936 at least. However, according to C. F. Doucette the infestation was practically negligible in 1936, there being but slight defoliation. While other factors may be associated with this decrease the indications are that it was due in a large part to the combined efforts of the introduced parasites, *Apanteles* and *Meteorus*. The parasitization of the overwintering larvae of 1934–35 by *Meteorus* amounted to 7 percent. Additional parasitization by the first-generation *Meteorus* on the larvae of later instars amounted to 17.3 percent. A widely taken sample of 1935–36 hibernacula from the same locality produced 31 percent parasitization by *Meteorus*, an increase of nearly 25 percent over that of last year. With the prospect of an exceedingly high first-generation parasitization during the summer of 1936, one can hardly question the importance of this parasite.

EFFECTIVENESS OF OTHER NATURAL ENEMIES

During the course of the season's study only a few species of native parasites were reared. One of these, a tachinid, *Tachinomyia similis* Will., was the most prevalent species and appears to be of considerable importance. It was present in nearly every locality where collections were made and occasionally in abundance. Parasitization by this species ranged from 0 to 41 percent for all points within the infested territory. If the importance of the species be measured in relation to the degree of infestation, as in the case of *Apanteles*, it will be found more effective in the lightly infested areas, where the average parasitization was 11.9 percent. In areas of medium infestation the parasitization became less, averaging 4.5 percent, and reached its minimum in the heavily infested area, where the average was only 2.7 percent. It appears likely that the species will suffer somewhat from competition with *Compsilura*. Its method of reproduction (i. e., egg deposition on host larva) is less effective than that of *Compsilura*, and the larval development is slower. However, since *Tachinomyia*

requires no alternate host, it has the advantage of *Compsilura* in this respect.

During 1935 negligible parasitization by another tachinid, *Exorista mella* Walk., was observed. Only 18 flies were bred from 8,387 larvae and pupae of *Stilpnotia salicis*. Occasionally *E. mella* is undoubtedly of importance, as indicated by previous records. It is a widely spread species which requires an alternate host, and its importance as a parasite of *S. salicis* is probably dependent upon the abundance of favorable overwintering hosts.

One other undetermined species of Tachinidae was reared in small numbers out of material from Stanwood. Its comparative abundance in one of the largest tracts of heavy infestation is noteworthy. Parasitization by this species in the locality where it was found amounted to 3.6 percent.

No native species of Hymenoptera were encountered in the dissections of early-instar larvae, and in only one instance was any reared from the late-instar larval collections. A single specimen, determined as a campoplegine, was obtained from Hoquiam.

The pupal collections, which were obtained from 16 localities, totaling 1,293 individuals, were productive of only one hymenopterous parasite. A single individual, determined as *Ephialtes* (*Itoplectis*) *atrocoxalis* Cress., was reared from the Stanwood material.

A total of 316 satin moth egg masses were collected from 10 localities. Eight of the thirty-two egg masses collected at Redmond produced adults of *Trichogramma minutum* Riley. Since the paratization was confined to a very few eggs of each mass, the effectiveness of the species, at least for 1935, can be considered negligible.

A number of predators (mites, pentatomid bugs, ants, etc.) were observed, but in no instance was any one of them numerous enough to warrant more than passing attention. It is possible that birds, particularly robins, destroy large numbers of the satin moth, but definite proof of their importance in this respect is lacking. Perhaps the strongest argument in their favor is the otherwise unexplained disappearance of larvae from small isolated infestations.

Winter mortality of the hibernating larvae, estimated at about 25 percent, was undoubtedly responsible for a large decrease in population. It is believed that this is primarily the result of unfavorable climatic conditions, although other factors (e. g., dense population) may be influential. In some cases the dead larvae were clothed with a white fungus which evidently was not the sole cause of death, since many other dead larvae from the same localities were quite free of it.

Another less important factor concerns the mortality in the egg stage caused by the premature dropping off of the egg masses from the leaves of the cottonwood. Such egg masses do not hatch properly, and the larvae from those that do hatch probably succumb before reaching food.

Purely local, but nevertheless of considerable importance in some localities, is the mortality caused by starvation. At Sumner the food supply was practically exhausted when most larvae were still in the penultimate instar and many larvae died from this cause.

Disease which frequently appears in connection with a severe outbreak of the satin moth was not present in any of the localities visited by the writer of this section.

CONCLUSIONS REGARDING VALUE OF INTRODUCED INSECT ENEMIES

It is reasonable to expect that within the next few years the satin moth will extend its range to its most southern limits. Eastward its progress should be much slower, owing in part to natural barriers. Injury, occasionally resulting in the death of some trees, has probably occurred and will recur, but no evidence exists in Washington of any extensive killing by this species. Since successive years of complete defoliation are the primary cause of injury, their future occurrence is less likely in view of the recently introduced parasites. According to the observations of those familiar with the satin moth in this section, there was a general decrease in population during 1935. Naturally there have been local fluctuations, particularly in urban areas where artificial control was practiced or where a shifting of the infestation occurred, but this was the first noticeable decline over the entire territory.

An intensive study of the control factors operating has revealed several of importance, but there is no proof that, except for the introduced parasites, they were any more effective during 1933 and 1934 than in previous years. Since the decline is coincidental with the tremendous spread and abundance of *Apanteles* in the field, it is reasonable to attribute this decline to the additional aid of this introduced species. Moreover, the results of the larval dissections show *Apanteles* to be a most effective agent, the parasitization ranging from 11 percent in the heavily infested areas to 32.8 percent in localities where the host was scarce. It is extremely doubtful if any of the other introduced parasites were at all influential except in the few localities previously mentioned. When they are more widely disseminated, however, material aid may be expected from these species.

SUMMARY AND CONCLUSIONS

The satin moth (*Stilpnotia salicis*) is common throughout Europe and at times severely defoliates poplar and willow. It was first discovered to be present in the United States in June 1920 when it was found near Boston, Mass. Two years later it was found at Bellingham, Wash. At present it occurs over practically half the total area of New England, nearly all of Washington west of the Cascade Range, and in northwestern Oregon. In both New England and Washington the satin moth was first observed as a pest of *Populus*, particularly those species introduced and planted for shade or ornamental purposes. Later native species of *Populus* in natural growths and species of *Salix* were attacked.

Soon after the satin moth was first discovered in New England it was found that it was being attacked by certain insects that had previously been imported as enemies of the gypsy moth and the brown-tail moth. Observations have shown that two of these (*Compsilura concinnata* and *Eupteromalus nidulans*) destroy large numbers of satin moth larvae. Observations suggest that *C. concinnata* is of more importance as an enemy of the satin moth in areas where the gypsy moth is not present in appreciable numbers than in areas where it is numerous. Native insect enemies have not been found to be important in controlling *S. salicis* in New England.

From 1927 to 1934, inclusive, seven species of Hymenoptera and Diptera, parasitic on the satin moth in Europe, were imported and liberated in satin moth infestations in New England. Only one of these (*Apanteles solitarius*) is known to have become established as an effective agent in reducing satin moth infestations in that region.

The three important introduced insect enemies, unusually low winter temperatures, spraying, fungi, and birds undoubtedly play leading parts in reducing infestations of the satin moth in New England. Observations indicate that the pest reached a peak in 1930 or 1931 and that defoliation, generally speaking, was much less severe from 1932 to 1934, inclusive. It is significant that one of the introduced insect enemies (*Apanteles solitarius*) was first recovered in promising numbers in 1930. It appears that its addition as a control factor was sufficient to reduce, at least temporarily, the numbers of the pest to such a degree that it was less noticeable and injurious from 1932 to 1934, inclusive.

Available information indicates that native insect enemies are not important in reducing the numbers of the satin moth in Washington. Ten species of insect enemies of European origin were liberated there from 1929 to 1934, inclusive. Some of these were collected in New England, where they were already established, while others came directly from Europe. Four of these (*Compsilura concinnata, Meteorus versicolor, Eupteromalus nidulans,* and *Apanteles solitarius*) are known to have become established. *A. solitarius* rapidly increased and spread. Dissections of satin moth larvae collected at various points in the State indicate that *M. versicolor* and *C. concinnata* have become of considerable importance as parasites of the satin moth at or near points in which they were liberated. This is of particular interest in connection with *M. versicolor,* since it is not known to have gained a foothold in New England.

Observations show that there was a general decrease in satin moth population in Washington in 1935. This decline is coincidental with a conspicuous abundance of *Apanteles solitarius,* and it is reasonable to attribute this decline to the additional aid of this introduced species.

Studies have shown that the introduction of insect enemies of the satin moth into New England and Washington has been of value. This applies especially to *Apanteles solitarius.* Finally, the successful establishment in Washington of foreign species that had already been satisfactorily introduced into New England further suggests the possibilities and value of similar attempts.

U. S. GOVERNMENT PRINTING OFFICE: 1938

For sale by the Superintendent of Documents, Washington, D. C. - - - - Price 5 cents